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ADVANCED DESIGN AIRCREW PROTECTIVE RESTRAINT SYSTEMS

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TECHNICAL REVIEW AND APPROVAL

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This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

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Next generation combat aircraft with advanced aerodynamic and controls features will have combat maneuver capability which will impose multiaxial acceleration forces on the aircrew. Advanced aircrew systems will be required for restraint, support, mobility and escape during these combat conditions. Two concepts, an articulating ejection seat (with advanced subsystems) and a small spherical capsule, are defined and compared. The concept based on the articulating seat was selected for further

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investigation and a full-scale rotatable mock-up was constructed for concept evaluation. The mock-up incorporated a "body fixation" system consisting of inflatable restraints and a contour-forming cushion and a "powered mobility" system which permits the backrest and headrest to be rotated for external visibility. A "next-generation" escape system is described but was not part of the mock-up. The fixation and mobility concepts were evaluated under $\pm$ 1 G_z and $\pm$ 1 G_y conditions. The concepts were considered to have considerable potential and it is recommended that they be incorporated in a test fixture which could be used in a centrifuge to investigate the effectiveness of the concepts under representative multiaxial acceleration conditions.

SUMMARY

This study is the initial phase of a program aimed at the development of advanced design aircrew systems for the next generation of Air Force combat aircraft. For these new aircraft, it is anticipated that combat operations will involve high multiaxial acceleration maneuvers and that new aircrew systems will be required for restraint, protection and escape under these combat conditions.

Two conceptual aircrew system approaches are defined and evaluated. One of the approaches is to use an advanced form of articulating ejection seat and the other is to accommodate the crewman in a rotatable spherical capsule. The concept based on the articulating seat was selected for further investigation using a full-scale mock-up. Elements of the concept which were incorporated in the mock-up included a "body fixation" system for restraint and support and a "powered mobility" system to facilitate external surveillance. Body fixation is achieved by a system of inflatable bladders and contour-forming cushions. Powered mobility is provided by lateral rotation of the backrest and headrest. The concept also includes an advanced escape system which will permit escape under combat maneuver conditions and will provide restraint against limb flail in ejections at high speed. The mock-up was used to evaluate the body fixation and powered mobility systems under $\pm 1\ G_z$ and $\pm 1\ G_y$ conditions with the articulating seat in the upright and reclined positions. It was concluded that these systems had sufficient potential to warrant further investigation. On this basis, it is recommended that these concepts be incorporated in a seat assembly which will be suitable for installation in the AMRL centrifuge and impact track facilities. Testing under representative high multiaxial acceleration conditions will provide information on the effectiveness of the restraint and mobility concepts and will form the basis for decisions on future development.

PREFACE

The work described in this report was performed under Air Force Contract F33615-78-C-0509 "Advanced Design for Aircrew Protective Restraint Systems." The Principal Investigator was A. Blair McDonald.

The Air Force Technical Monitor was Major James H. Raddin of the Biomechanical Protection Branch, Biodynamics and Bioengineering Division.

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INTRODUCTION

It is anticipated that the next generation of Air Force combat aircraft will have maneuver and flight envelope capabilities which are significantly greater than those of present combat aircraft. This projection is based on current design technology trends which include innovations such as the High Acceleration Cockpit (HAC) and advances in aerodynamic and control techniques which utilize direct lift, direct side force and drag modulations. The implication of these advances is that in the combat environment the aircrew will be subjected to high multiaxial accelerations and a primary problem will be to restrain and protect the crewman so that he can operate and perform effectively in this environment. In addition, it is clearly desirable that safe escape should be possible in emergencies which occur in the combat environment and throughout the expanded flight envelope projected for these future aircraft.

The anticipated requirements for the next generation of aircraft cannot be satisfied by current aircrew systems. Aeromedical research has been conducted on the problems associated with high + G_z acceleration during conventional attack combat maneuvers. This research has defined the advantage of reclining the seat back angle to increase the crewmember's ability to operate under the high + G_z conditions, and the approach has been to achieve the recline posture by the addition of an articulating mechanism to conventional ejection seat systems. It has been assumed that only minor modifications would be required to adapt existing systems to provide adequate restraint. The research has not yet fully addressed the body support and restraint problems that are introduced by the coupling of other aircraft maneuvering technologies with this approach, nor has it addressed the additional problems associated with emergency escape, particularly under operational maneuver conditions.

This study is the first phase of a program to develop aircrew restraint and body support systems which will provide adequate fixation of the torso and limbs during the application of high multiaxial acceleration forces and an aircrew escape system which will provide protection and escape in emergencies throughout the maneuver and flight envelopes. In this study, two basic conceptual approaches are defined and evaluated. In one concept an articulating ejection seat is equipped with a system of inflatable bladders and contour-forming cushions to provide restraint and with a powered mobility system to permit external surveillance during high acceleration conditions. In the second concept, the crewman is seated cross-legged in a small spherical capsule. The capsule tilts aft for high + G_z protection and rotates laterally for G_y protection and external surveillance. Both concepts incorporate advanced systems for aircrew escape.

The program consists of a study phase and a mock-up phase. In the study phase the two concepts were defined and a literature search was made to obtain relevant aeromedical design data. A comparative evaluation of the concepts was conducted and the concept based on the articulating seat was selected for further study in the second phase of the program in which a full-scale mock-up was constructed for concept demonstration and subjective evaluation.

REQUIREMENTS

The requirements specified for this program consist of performance and design goals based on maneuver and flight envelopes and of design constraints in the form of general ground rules and physiological limits.

RESTRAINT SYSTEM

The primary requirement for the restraint system is to provide satisfactory restraint under the high acceleration maneuver conditions associated with air-to-air and air-to-ground combat operations. The specified acceleration environment consists of any multiaxial combination of the following forces:

Anteposterior G	G_x: $\pm$ 3 G
Lateral G	G_y: $\pm$ 5 G
Vertical G	G_z: + 10.5 G, -3.5 G

An equally important factor is the requirement to provide for aircrew mobility during conventional flight and combat conditions.

AIRCREW ESCAPE

The major requirements for the escape system are to provide an escape capability under the multiaxial acceleration maneuver conditions and also throughout the projected flight envelope (Mach 6, 150,000 feet and Q = 1600 PSF) illustrated in Figure 1. The emergency requirements include the provision for windblast protection in the event of inadvertent loss of the aircraft canopy.

The physiological limits for forces imposed on the aircrew during escape are stated in terms of acceleration limits on the seat and are:

G_x:	$\pm$ 40 G
G_y:	$\pm$ 20 G
G_z:	+ 25 G, -15 G

AIRCRAFT INTERFACES

To ensure compatibility between restraint and protection system concepts and the aircrew primary interfaces, it is required that the concept be compatible with backrest articulation (13° to 65°) and with the employment of side-stick controllers, rudder pedals and Heads-Up Display (HUD).

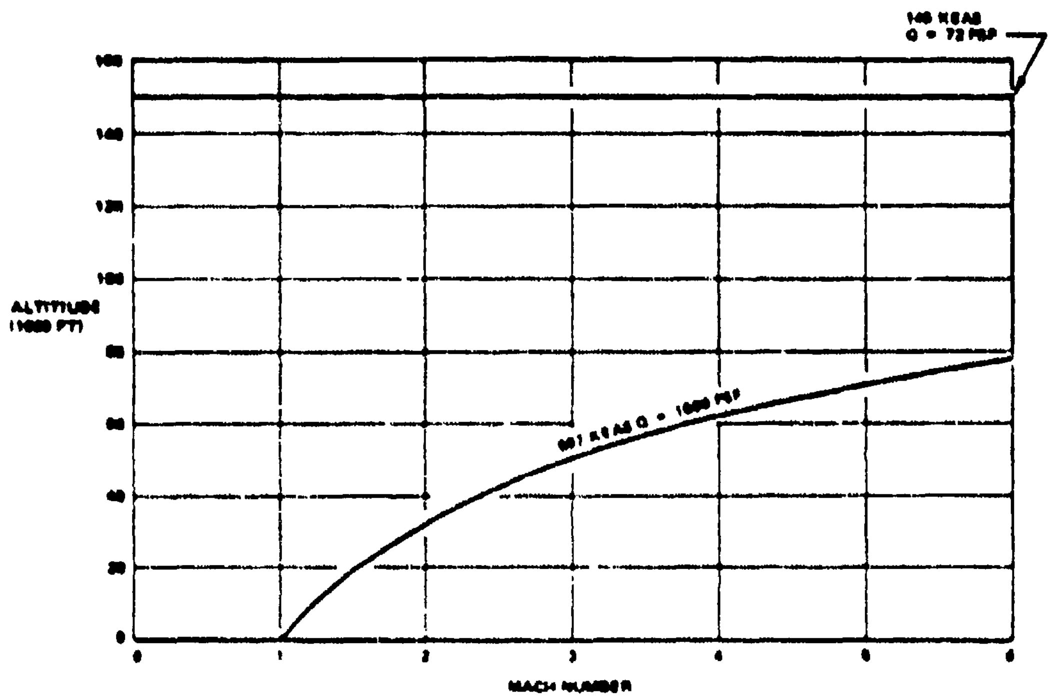


FIGURE 1. FLIGHT ENVELOPE

LITERATURE SEARCH

A literature search was conducted to obtain design data on aircrew restraint and protection provisions in general and to obtain information concerning the specific characteristics of the two concepts being studied in this program. Due to the unconventional and diverse features of the concepts being investigated, the litrature search covered a relatively wide range of subjects. Subjects of a general nature included: aircrew restraint, aircrew protection, high speed-high altitude escape, windblast protection and high acceleration aircraft. Subjects related to the concept characteristics included: posture, acceleration effects, disorientation and coriolis effects. The primary sources searched were the libraries of the McDonnell Douglas Corporation, National Aeronautics and Space Administration and Defense Documentation Center.

In the course of the literature search a substantial volume of material was reviewed. It was found that the quantity and relevance of the information available varied widely throughout the range of subjects. Some subjects were found to be well documented while on others little or no information was available. In the case of some subjects, particularly in the biomedical category, there was a great deal of information available but little of it was directly applicable or relevant.

A summary of the results of the literature search, including identification of areas where there was a lack of information, is given in the following paragraphs:

AIRCREW ACCELERATION PROTECTION

The literature provides information on the substantial research and development effort which has been carried out in recent years to investigate biomedical and performance effects of high $+G_z$ acceleration on aircrew and to study methods of increasing aircrew tolerance to these forces. Conventional aids to high G_z protection, anti-G suits and breathing-straining techniques, have been the subject of renewed interest and study (Refs. 1, 2 and 3) although the primary effort has been devoted to the investigation of the HAC concept in which increased tolerance is achieved by raising the crewman's pelvis so that he is in a reclined posture and the head-aorta hydrostatic blood column is reduced. A review of $+G_z$ protection methods is contained in Reference 4 and References 5 through 11 describe the $+G_z$ acceleration protection advantages of the reclined posture.

In terms of seat design, the general approach is that the crewman should be reclined to the maximum backrest angle compatible with the crewman being able to maintain control of the aircraft. In the literature, the consensus is towards the adoption of a backrest angle of 65 degrees and this backrest angle was specified for the concepts in this study. However, one investigation, Reference 12, in which tracking performance was correlated with + G_z level and backrest angle, produced evidence which indicated that a backrest angle of 50 degrees may be a superior solution. This would significantly reduce the degree of seat articulation required, especially if this reclined configuration could be coupled with an increased backrest angle for the upright seating position. It should be noted that there appears to be a lack of available information in the literature concerning the characteristics of the upright seated positions relative to future high-maneuverabilty aircraft.

Acceleration data related to combat maneuvers is almost entirely concerned with high + G_z effects. However, one source, Reference 13, reports on a study to investigate the effects of high $\pm$ G_y acceleration due to the use of direct side force. Centrifuge tests were conducted and although the applied lateral acceleration was relatively low (in comparison with the $\pm$ 5 G_y specified for the restraint concepts in this study), the conclusions included a recommendation for improved lateral support.

Two sources in the literature (Refs. 10 an 11) indicate that providing support for the sides of the chest aids breathing during high + G_z conditions. In the concept definition phase of this program, both concepts were intended to have inflatable supports for the sides of the chest. However, in the mock-up evaluation phase of the program, it was found that the chest supports were impractical because of unacceptable interference with arm movement when the seat was in the upright configuration.

The literature search did not uncover any information relative to the characteristics of a cross-legged posture, as proposed for the capsule concept, with regard to acceleration tolerance. One study, Reference 9, indicated that having the legs raised, in addition to the pelvis, may be beneficial to comfort and tolerance under high + G_z conditions.

In early work on the effect of G_z acceleration on vision, References 14 and 15, it was demonstrated that the acceleration levels at which vision degradation symptoms occurred could be increased by applying suction to the eyeballs. In high + G_z maneuvers the crewman's external visibility is reduced by dimming and loss of peripheral vision and by restricted mobility due to the effect of the acceleration forces on the body. It appears that it would be feasible to augment the effectiveness of mobility aids, such as the rotating capsule or powered mobility concepts being evaluated in the study, by the application of this principle to delay the onset of dimming and the loss of peripheral vision.

CREWSTATION DESIGN

Information generated by the USAF-funded HAC and Advanced Fighter Technology Integration (AFTI) programs (Refs. 16 through 21) provides a comprehensive bank of data relative to the design and operational aspects of the crewstation for a high maneuverability aircraft. This data provided the baseline information for the configuration of the restraint and mobility concepts in the study. This information was particularly applicable to the concept based on an articulating seat and was used to establish the geometry of the articulating seat surfaces and the location and adjustment of the side-stick controller, throttles and rudder pedals.

RESTRAINT

The literature search produced a considerable quantity of data on aircrew restraint systems although the majority of the information available relates to existing strap-type arrangements which were not designed to provide restraint under high multiaxial acceleration flight conditions. Restraint development relative to the AFTI program is reported in Reference 19. This was used as baseline design for the basic strap-type restraint system for the study concept which is based on the use of an articulating seat. For the capsule concept a basic strap-type harness is required. The requirements for this portion of the restraint system are similar to those for a capsule or non-ejectable seat and several suitable approaches are described in Reference 22.

In the study concepts, inflatable bladders are used to support and restrain the crewman under high multiaxial accelerat1ion conditions. The literature search produced information on several applications of inflatables for aircrew restraint however, in all cases the objective was to provide protection against crash forces and the design data was not relevant to the study concepts.

AIRCREW ESCAPE

The principal areas of interest are the environment extremes of the escape envelope specified for the study concepts, shown previously in Figure 1, and factors affecting escape under high multiaxial acceleration conditions. The high altitude portion of the envelope applies only to the capsule concept as human limitations restrict the articulating seat concept to a maximum of approximately 60,000 feet.

High Altitude Escape

For escape at high altitude the available literature, References 23 and 24, describes the recovery environment for specific vehicles under specific conditions at the initiation of the escape sequence. This data is of general interest but is not directly applicable to the spherical capsule because the recovery environment is highly dependent on the aerodynamic characteristics of the capsule and on the altitude and speed conditions at the initiation of escape.

High Speed Escape

For escape at high speed the primary concern with regard to the study concepts is the provision of aircrew windblast protection on the articulating seat concept. Reference 25, on the basis of open ejection seat injury statistics, describes the need for windblast protection for ejections at speeds above 400 KEAS.

The available literature provides information on many aspects of windblast protection. Research into the aerodynamic forces associated with limb flail has primarily been sponsored by the Aerospace Medical Research Laboratory. This work is described in References 26 through 30. In one of these programs, Reference 27, it is concluded that the seat must be aerodynamically stable to permit satisfactory protection against flail. In the case of the articulating seat concept this philosophy should be satisfied by the fast-acting inflatable stabilizer.

References 31 through 34 describe several limb restraint concepts and hardware systems. The approach for leg restraint in the articulating seat concept is to provide both passive and active systems. The passive system consists of extended seat sides to prevent excessive lateral motion of the legs and Reference 31 advocates that this method include lateral support for the feet. With reasonable seat stability the passive restraint system in the articulating seat will prevent limb flail and the active system, a conventional strap and garter arrangement, is included to prevent unwanted leg motion during the application of the stabilizer and decelerator forces. The arm restraint concepts described in the literature are of two basic types. In one approach the arms are constrained by cables which are retracted during ejection and in the other the motion of the arms is restricted by nets which are deployed at the sides of the seat. The proposal to use inflatable bladders for arm restraint in the articulating seat concept appears to be a unique solution and the available literature does not contain any relevant design data for such an arrangement.

Escape at high speed raises a question regarding potential problems due to aerodynamic heating, particularly with regard to the articulating seat concept where the crewman is exposed to the airstream. For this concept, the altitude capability is limited and for a Q of 1600 psf the maximum Mach No. will be less than Mach 4. Reference 35 indicates that aerodynamic heating will not be a problem at speeds less than Mach 4.

Ejection Under Multiaxial Acceleration Conditions

The literature search did not produce any data on escape under multiaxial acceleration condition but did provide information on the effect of acceleration in some individual axes. One analysis, Reference 36, indicates that a conventional catapult can eject the crewman under high + G_z acceleration conditions but that the spinal forces become excessive. Tests under - G_z acceleration conditions, Reference 37, showed satisfactory operation of a conventional propulsion system at levels up to - 10 G. Data is also available on the effect of - G_x acceleration and the analysis and tests reported in References 38 and 39 show degradation of the ejection trajectories. On the basis of these data, advanced propulsion systems are proposed for both of the study concepts.

AIRCREW POSTURE

A specific area of interest was to obtain information on the unique cross-legged posture proposed for the crewman in the rotating capsule concept. Not surprisingly, there was no evidence in the literature that this posture has ever been used in an aircraft. However, the literature search revealed many instances in the past where an unconventional posture, usually the prone position, was used to obtain aircraft performance advantages. Examples found, References 9 and 40, were the FS 17 research glider, Berlin B9, BV 40 glider, Ba 349 glider trainer, Arado E 381, Heinkel P1077 and the Northrop XP-79. The literature did not provide any information on the biomedical aspects of these crewstation arrangements.

ACCELERATION - DISORIENTATION - CORIOLIS

There is a great deal of information available concerning problems related to aircrew disorientation and the factors involved. A review of the more relevant sources, References 41 through 47, indicates that any aircrew arrangement which involves motion of the pilot's head or a change in the acceleration environment, introduces a risk of spatial disorientation. However, in relation to the concepts being studied in this program, in which the head is close to the center of rotation, it is not evident that the probability of disorientation will be significantly different from the probability arising from the normal head movements employed during external surveillance.

One investigation of disorientation occurrences, Reference 48, concludes that disorientation is a common experience and that in almost all cases the visual system is the one affected with the highest incidence of disorientation being at night, with IFR conditions or when flying wing formation. This source also concludes that the incidence of disorientation is the same for straight and level flight as for maneuver conditions.

In the data, the close association of the body and vehicle axes is stressed. In the concepts being studied, rotation causes the body axes to move relative to those of the aircraft. This situation is not addressed in the available literature, although in Reference 49, flight tests are described in which rotation in pitch during high + G_z conditions did not cause disorientation.

SEAT CUSHION

In both of the study concepts, the use of contour-forming cushions is proposed to aid comfort and to assist body "fixation" during the application of acceleration forces. This concept was investigated and developed by AMRL for use in astronaut support systems, Reference 50, in which the contour forming and impact attenuation characteristics of this design were particularly attractive.

In the capsule concept the contour forming cushion will help to ensure long-duration comfort with the cross-legged posture and the impact attenuation characteristics will be of value during ground impact. However, the immobility of the legs will degrade blood circulation which would, in turn, degrade acceleration tolerance. To combat this, it is proposed to introduce a pulsating cushion (Refs. 51, 52 and 53) or pulsating anti-G suit bladder to maintain circulation.

CONCEPT DESCRIPTION

The two concepts under evaluation, one based on an advanced form of articulating ejection seat and the other on the use of a spherical capsule, are described in the following paragraphs. Both concepts address the requirements for restraint, protection, mobility and escape under high multiaxial acceleration conditions. The capsule can meet the escape envelope requirement whereas the articulating seat has limited altitude capability unless pressure suits are worn.

ARTICULATING SEAT CONCEPT

General

In this concept an articulating seat is equipped with additional systems to provide the required restraint, protection, mobility and escape capability for high-G maneuver conditions. The baseline seat is assumed to be an articulating version of the ACES II seat which was proposed by MDC for the HAC and the AFTI program applications. The basic ACES II seat is currently in production for the A-10, F-15 and F-16 aircraft while an advanced version, which incorporates an active limb restraint system, is used in the latest B-1 flight test aircraft. In the articulating seat, Figure 2, the seat pan and backrest articulate about a fixed shoulder pivot point to recline the backrest from an upright seating angle of 15° to a reclined angle of 65°. Relative to the baseline seat, the following major features are introduced:

- A system of inflatable bladders to provide body and limb fixation.
- Contour-forming seat and backrest cushions to aid body fixation.
- A powered backrest and headrest rotation system to provide mobility for external surveillance.
- An advanced escape subsystem.

A detailed description of the above features is given in the following paragraphs:

Restraint System

Restraint is provided by a strap inertia reel system, the inflatable bladder system and the contour-forming cushions. These provisions act together and complement each other to provide the necessary level of restraint for all flight conditions.

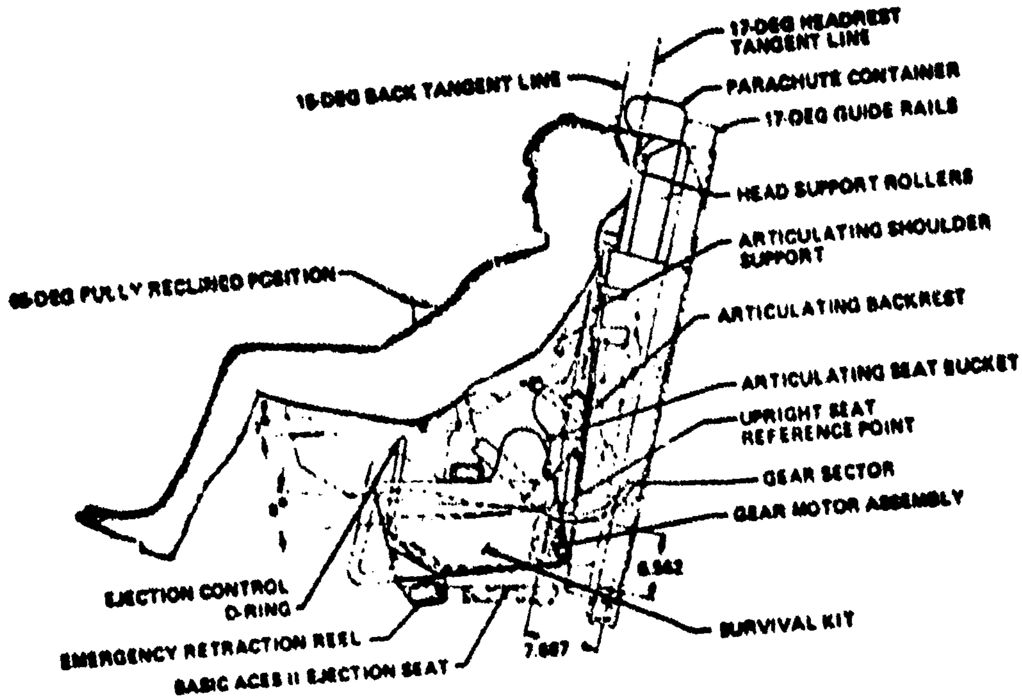


FIGURE 2. ARTICULATING SEAT GEOMETRY

Strap Restraint System

The configuration of the basic strap and inertia reel restraint system is shown in Figure 3. The system consists of a lap belt, shoulder straps and chest straps which are used in conjunction with a torso harness. This system is identical to that used in the ACES II seat except that the lap belt has been altered to provide restraint against submarining when in the reclined position, and chest straps have been added to aid lateral restraint. The torso harness is a standard Air Force PCU-15/P harness modified by the addition of the center lap belt segment and by the addition of rings for attachment of the chest straps. Extension and retraction of the shoulder and chest straps are controlled by independent inertia reels.

Inflatable Restraint System

The inflatable restraint system, as depicted in Figure 4, consists of bladder installations at the lower torso, shoulders, forearms and thighs. The bladders are mounted on structure and when they are inflated they tend to hold the body in position and to provide support and restraint against the maneuver forces. The lower torso and shoulder bladders are installed on forward projections of the backrest and the leg restraint bladders are mounted on the inboard surfaces of the seat bucket.

The forearm bladders are mounted within trough-shaped armrests and these bladders are of double-cylinder construction so that the arm can be enclosed and held in position without the application of a high pressure which would interfere with operation of the throttle and side-stick controller.

Contour-Forming Cushions

The seat and backrest pads are of a "contour-forming" cushion design which will allow each crewmember to form the contours of the seat and backrest pads to obtain an individual fit. The exact fit of these pads will help to fix the position of the body relative to the seat and to provide support during the application of lateral forces. Each contour-forming cushion consists of a fabric cover which is filled with "microbeads". The cover is of stretch nylon-frothed neoprene fabric (used extensively in wet-suit fabrication) and the "microbeads" are of expanded polystyrene. The contour forming is obtained by pressurizing and then creating a partial vacuum within the cushion. Pressurization allows the "microbeads" to float within the cushion and to form around the contours of the crewman. Evacuation of the cushion causes the microbeads to "lock" together forming a relatively rigid contoured mass.

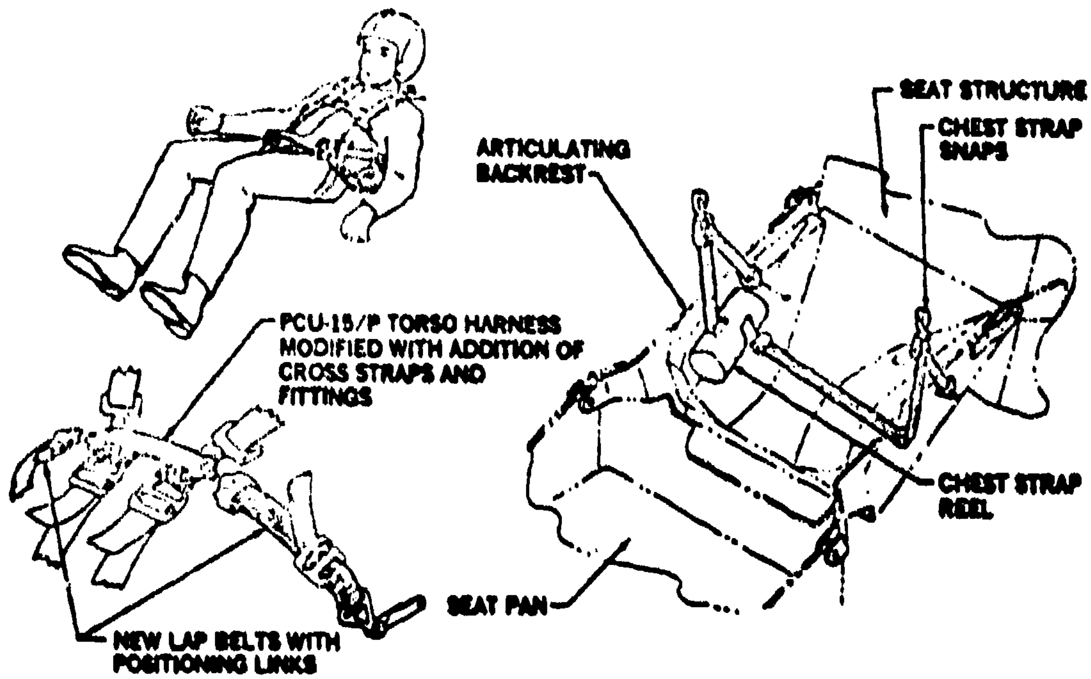
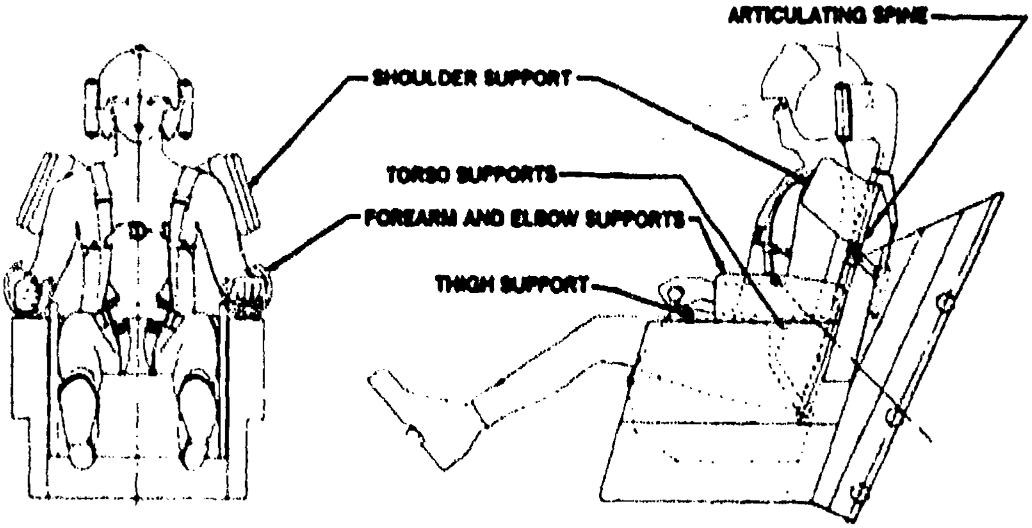


FIGURE 3. BASIC STRAP RESTRAINT SYSTEM - ARTICULATING SEAT



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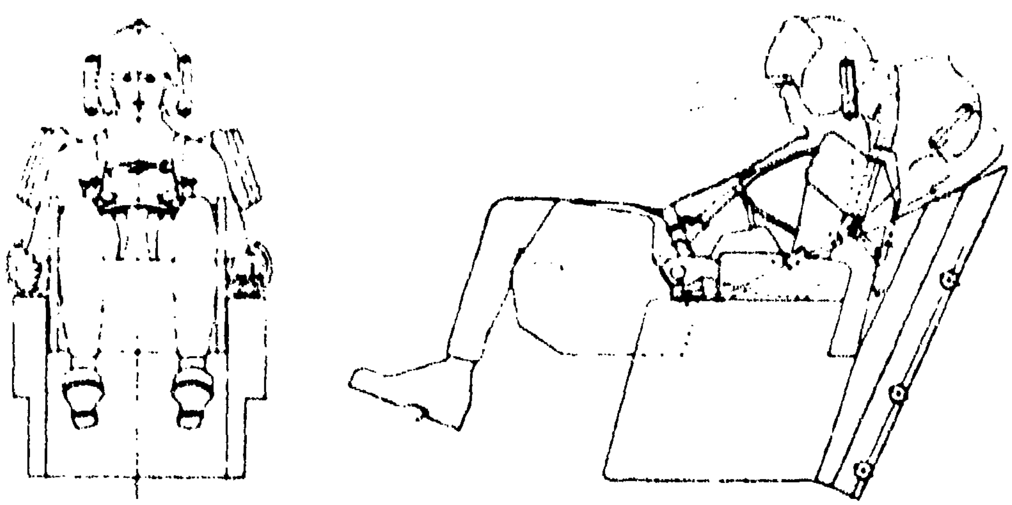

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FIGURE 4. INFLATABLE RESTRAINT SYSTEM

In operation, the crewman would conform the cushions prior to takeoff and could then reset them at any time throughout the flight. An automatic pressurization-evacuation cycle could be used following articulation to reset the contours with the crewman in the new position.

Powered Mobility System

This system allows the fully restrained crewmen to select powered rotation of his head and upper torso for external surveillance or target tracking. The system is controlled by a switch on the side-stick controller and consists of actuators which rotate the headrest and upper portion of the backrest in the desired direction. The backrest is split into three segments. The lower segment is hinged from the seat pan and is fixed while the upper two segments can rotate about a central structural spine. The center segment is free to rotate under pressure from the torso when the rotation system is selected.

Escape System

The escape system provides for ejection under multiaxial acceleration conditions and includes restraint against limb flail at high speed.

Escape under Multiaxial Acceleration

Current escape systems are not satisfactory for ejection under high acceleration conditions. In a high + G_z environment the catapult imposes excessive force on the spine yet the propulsion system will not provide tail clearance at high speed. Also, high G_y or G_x forces can cause instability and unacceptable trajectory variations. To overcome these problems it is proposed to equip the articulating seat with a variable thrust-impulse propulsion system, with an inflatable stabilizer and with thrust-vector control. The introduction of variable propulsion and thrust vector control dictates the use of a relatively sophisticated system of controlling the selection and operation of these subsystems. The resulting seat system is essentially a "next-generation" ACES II system and includes the following primary features:

- Control System - The operation of the seat subsystem is governed by an electronic control system which, as shown schematically in Figure 5, receives environment inputs from the aircraft systems and from seat-mounted sensors. On the basis of the environment data the control system, which includes redundant microprocessors, selects the recovery mode and the subsystem operation appropriate to the ejection conditions. During ejection and recovery the control system continues to monitor the environment and control subsystem operation.

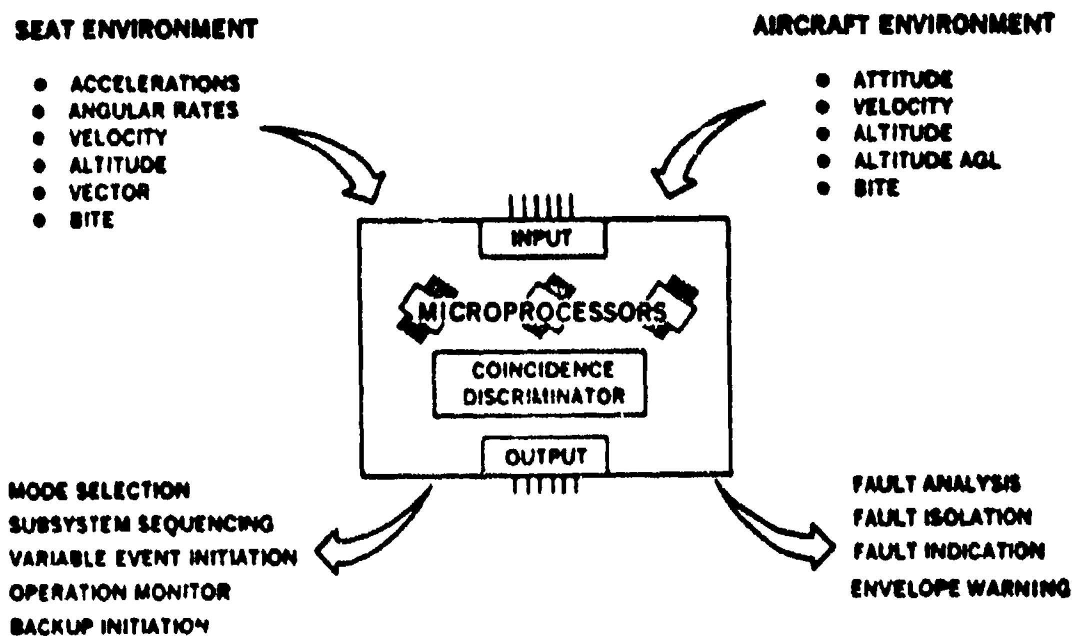

FIGURE 5. ELECTRONIC CONTROL SYSTEM

- o Propulsion - The propulsion system provides a range of catapult thrust levels and a range of rocket impulse levels. In a simple approach, this is achieved by using multiple catapult cartridges and multiple rockets. The control system, on the basis of the sensor inputs, selects the thrust and impulse levels appropriate to the conditions. In high + G_z acceleration conditions a low catapult thrust would be combined with a high rocket impulse.

- o Stabilization - Stabilization is achieved by a combination of inflatable stabilizer and thrust vector control. At high speed, the rapid deployment characteristic of the stabilizer prevents excessive attitude excursions, while at low speed this function is achieved by control system commands to the thrust vector control system.

- o Deceleration - Deceleration from high speed could be provided by a drogue or, as illustrated in Figure 6, by progressively adding drag area to the inflatable stabilizer with the rate of deployment being governed by the control system.

- o Recovery Modes - In high speed - low altitude conditions the seat and crewman are decelerated prior to deployment of the recovery parachute whereas at low speed and low altitude, the recovery parachute is deployed as the seat emerges from the aircraft. For high altitude the deployment of the recovery parachute is delayed.

- o Options - The use of a microprocessor control system introduces the computation capacity to perform many additional functions such as self-test, fault isolation and envelope warning. However, perhaps the most important option available is to program the control system to select a "soft-ride" recovery when the ejection conditions do not justify a maximum performance sequence.

Restraint Against Limb Flail

Arm restraint is provided by the inflatable restraint system and leg restraint by a conventional strap and garter arrangement. Ejection is initiated by controls on the throttle and side-stick controller and thereafter the forearms are retained by inflation of the restraint bladders. For ejection the inflation pressure is increased over that used for normal restraint purposes. The pressure is released prior to seat-man separation. The leg restraint straps pull the legs back against the seat front during the catapult stroke and they are retained until actuation of the seat-man separation system. Additional leg retention is provided by forward extensions of the seat sides.

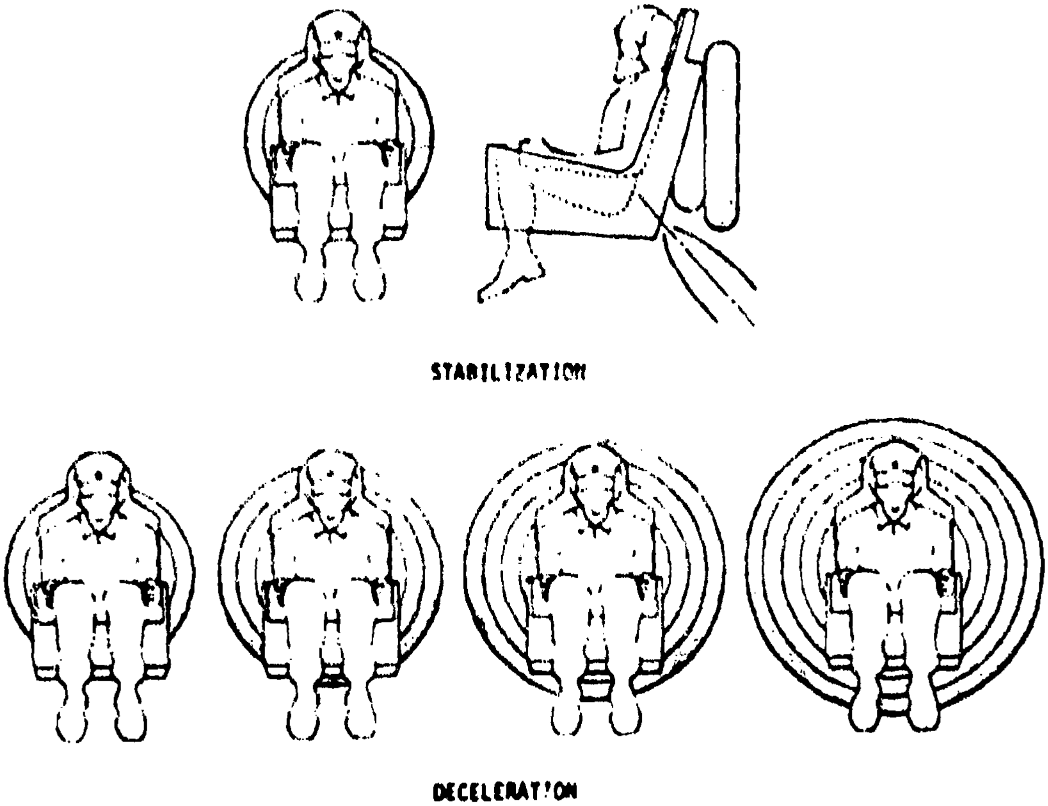

FIGURE 6. INFLATABLE STABILIZATION-DECELERATION SYSTEM

SPHERICAL CAPSULE CONCEPT

General

In this concept, the crewman is housed in a small spherical capsule, Figure 7. The capsule is sealed and pressurized and serves as the crewstation and escape vehicle. The capsule rotates in pitch to obtain recline and rotates laterally to reduce the effect of lateral forces and to facilitate external visibility. The rotational features dictate the use of a spherical shape for the capsule and, in order to obtain a capsule size which is acceptable, the crewman is seated cross-legged. Assuming the use of fly-by-wire controls for rudder and brakes, there is no fundamental reason why a cross-legged posture is not feasible and practical although special provisions are considered necessary to avoid discomfort and anticipated circulatory problems.

Capsule Description

The capsule is a 42-inch diameter sphere. The upper portion of the sphere is transparent and hinges open for ingress and egress. The lower portion is of monocoque construction. The crewman is partially enclosed by a backrest-bulkhead assembly and by side consoles which contain the throttle and side-stick controller.

The capsule installs in the cockpit beneath a conventional canopy. Capsule rotation from a backrest angle of 15° to 65°, to increase crewman tolerance to + G_z, results in a reduction in the height of the eye position. To compensate, the capsule is located relatively high in the cockpit, Figure 8, so that external vision is satisfactory when the capsule is in the reclined position. The capsule transparency is formed of two shells with an interlayer. This type of construction will ensure adequate strength while providing good optical properties. The capsule is pressurized and this eliminates the need for cockpit pressurization. It may also be practical to pressurize the capsule to a sufficiently low altitude that an oxygen mask need only be donned for emergencies or in the event that pressure breathing is a requirement. An additional possibility is that the capsule may be assumed to carry the bird-strike requirement thereby permitting a reduction in the windshield capability.

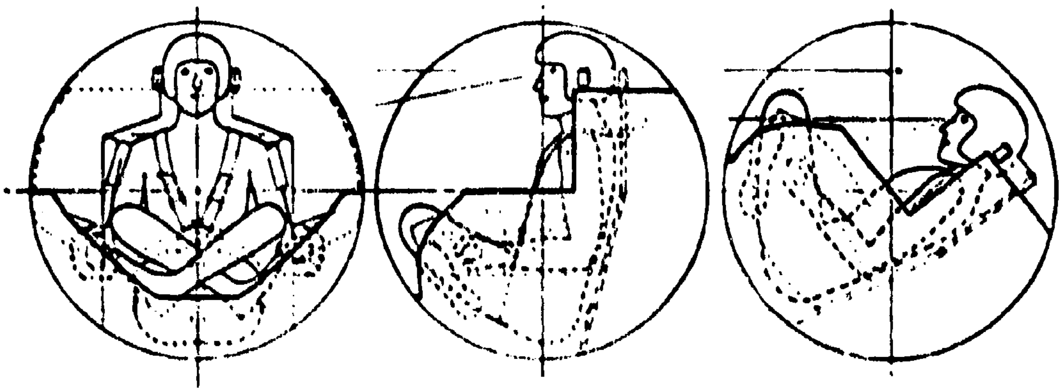

FIGURE 7. SPHERICAL CAPSULE CONFIGURATION

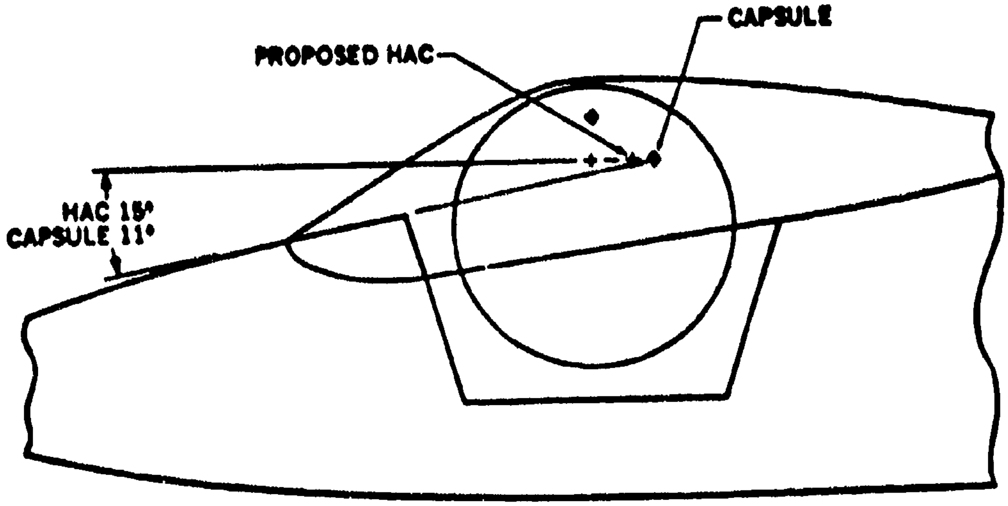

FIGURE 8. RECLINED EYE POSITION CAPSULE

The capsule is mounted in the cockpit by means of a pivot shaft at the base of the capsule. The capsule rotates about the shaft to accomplish two objectives:

- o During the application of lateral acceleration forces the capsule rotates so that a portion of the lateral force on the crewman is taken by the backrest. For this purpose, rotation can be selected to be automatic and is limited to ± 30 degrees.

- o The second purpose is to permit the crewman to swivel the capsule for external surveillance, target acquisition and target tracking. Rotation is controlled by the crewman and a sweep of ± 135 degrees is proposed.

The lateral pivot shaft is mounted on a trolley which runs in a curved track in the cockpit so that the capsule can be rotated for recline. Rotation to the reclined position is selected by the crewman or can be preselected to be automatic when the + G_z acceleration exceeds a predetermined value.

Controls and Displays

All aircraft controls and display controls are within the capsule. Flight control is full fly-by-wire. Console space within the capsule is extremely limited and multipurpose controls are used for displays and aircraft subsystems. The Heads-Up Display (HUD) contains all of the information required for combat operations. The display is projected onto the capsule transparency or onto a helmet-mounted visor so that the display is available to the crewman at all capsule positions.

Restraint

Basic restraint is provided by a conventional lap belt shoulder and crotch strap harness and inertia reel arrangement which would be similar to those used in current capsule escape systems or in other non-ejectable seat applications.

Additional aircrew restraint and support is provided by contour-forming cushions and by an inflatable restraint system. The seat and backrest pads are conforming cushions which, as described previously, can be contoured to the shape of the individual crewman and thereby provide support and stability. The inflatable restraint system consists of bladders to restrain the torso and arms. The crewman is partially enclosed by the backrest bulkhead and console structure and torso fixation is provided by inflatable bladders at the waist and at the shoulders. Arm restraint and support is achieved by bladders mounted within arm-rest troughs. The operation of this system is similar to that described in the articulating seat concept.

Comfort

The crewmember, in the cross-legged posture, is seated and supported by a deep contour-forming cushion which will permit the crewman to mold the cushion to the shape of his buttocks and legs. This will spread the support pressure evenly over all of the parts in contact with the cushion and will prevent the discomfort of pressure points. The cushion can be reformed as desired to accommodate changes in posture. Long durations in the cross-legged position could adversely affect the circulation in the legs which could, in turn, have an adverse effect on the crewman's ability to withstand high + G_z acceleration forces. To promote good circulation the crewman is equipped with an anti-G suit which is modified by the addition of a pulsating pressure system. This will function in a similar manner to pulsating seat cushions and can be selected by the crewman to stimulate circulation.

In other respects the capsule will have superior comfort relative to current open ejection seats as the crewman is provided with a "shirt-sleeve" environment.

Escape System

The crewman is ejected and recovered within the capsule. The capsule provides full protection against bird-strike and canopy loss and has an escape capabililty encompassing the complete maneuver and flight envelope projected for future aircraft. The escape and survival system components are packaged aft of the backrest bulkhead.

Ejection

The capsule is ejected in the reclined position and is automatically rotated to this position prior to ejection. Rocket propulsion is used with the thrust vector being essentially normal to the spine. This permits the application of relatively high thrust levels so that tail clearance under high + G_z conditions will not be a critical factor.

Ejection is initiated by the actuation of switches on the throttle and side-stick controller. Following initiation, the capsule is locked in the recline position, the canopy is jettisoned and the inertia reel and inflatable restraint system are activated. With the capsule locked in the recline position, ejection supports, which are mounted in fore-and-aft guide rails, lock into the capsule structure. The rocket propulsion system is then ignited and the capsule is ejected. The ejection supports disengage and remain on the guide rails.

Subsystems

The capsule subsystems are similar to those provided in the articulating seat concept. An electronic system (microprocessors and sensors) controls the operation of the system and selects recovery modes and options to optimize the recovery sequence to suit the emergency conditions. Thrust vector control and an inflatable stabilizer provide stabilization and trajectory control for ejection under multiaxial acceleration conditions. The crewman is recovered in the capsule. The capsule descends with the crewman lying on his back and the ground impact forces are attenuated by the inflatable stabilization-deceleration system and by crushable structure. The capsule is a survival shelter on land and in water. The recovery sequence is illustrated in Figure 9.

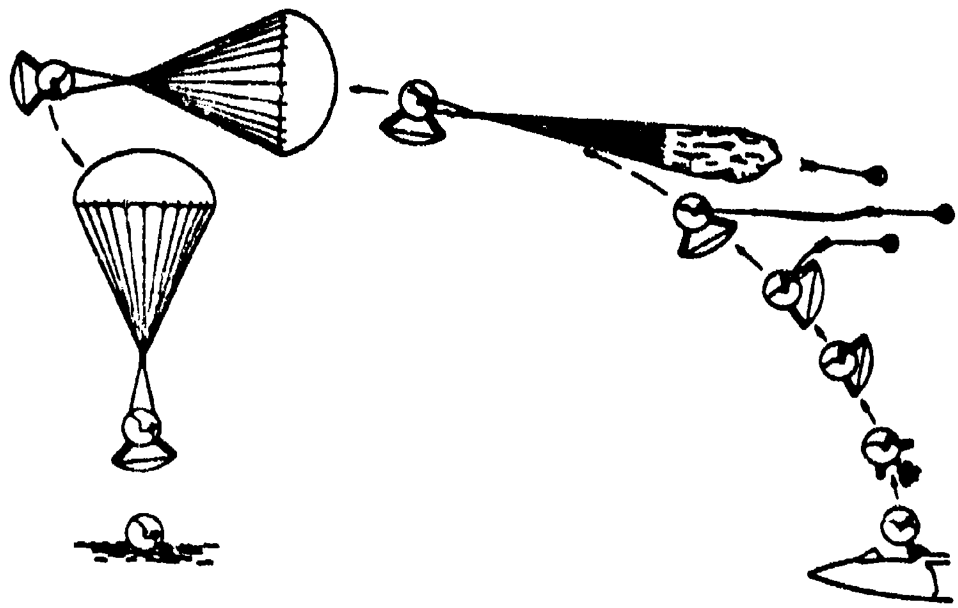

FIGURE 9. CAPSULE HIGH SPEED RECOVERY SEQUENCE

CONCEPT EVALUATION AND SELECTION

A comparative evaluation of the two concepts was conducted and the concept based on the articulating seat was selected for further investigation in the full-scale mock-up phase of the program.

A technical evaluation of the two concepts, presented in the Appendix, rated the capsule concept higher than the articulating seat concept. This was primarily due to the superior escape envelope capability of the capsule. The capsule rating also benefited from the mobility provided by the lateral rotation capability, although the combat utility of this feature has not been established. In the overall evaluation, the articulating seat concept was considered to be technically acceptable. The selection of this concept for the mock-up phase of the program was heavily influenced by the fact that it was considered to have a much higher probability, than the capsule, of resulting in successful aircrew system development in time for incorporation in next-generation aircraft. This conclusion was based mainly on the following factors:

1) The articulating seat concept is a combination of several subsystem concepts which are essentially independent. As a result, the total technical risk is relatively low. In contrast, the capsule has several innovative approaches which are interdependent and therefore the technical risk is high. Because of this high technical risk, it would be advisable to pursue a parallel program to develop back-up alternative approaches.

2) Development of the capsule concept would require a relatively extensive program and, due to the important relationship between the capsule features and aircraft operation, it would probably be necessary to demonstrate the system by flight test prior to a decision regarding incorporation in a production aircraft program.

3) The capsule has a major impact on the aircraft configuration and therefore would have to be considered in the preliminary design phase of the aircraft program. In view of the probable scope of the development program, there is a serious doubt that the capsule concept could be developed in time for next generation aircraft.

CONCEPT EVALUATION MOCK-UP

A full-scale mock-up was constructed for demonstration and evaluation of the aircrew restraint and mobility aspects of the articulating seat concept. The advanced design concepts incorporated in the mock-up are:

- o Inflatable restraint system
- o Contour-forming seat cushion
- o Powered backrest and headrest mobility system

DESCRIPTION

The mock-up, as shown in the photograph in Figure 10, consists of a seat-cockpit assembly which is pivoted in a stand so that the assembly can be rotated around the longitudinal axis. The seat bucket and backrest can be located to provide an upright or reclined seating configuration. The rotation and alternate seating configuration features permit the effectiveness of the restraint and mobility systems to be demonstrated and evaluated under G_z and G_y acceration forces of $\pm$ 1 G with the seat in either the upright or reclined positions.

The restraint system, the powered mobility system and the contour-conforming seat pan cushion installed in the mock-up were previously described. To enable a valid evaluation of these features,the primary crewman-cockpit physical interfaces, throttle, side-stickand rudder pedal controls are included in the mock-up. To accommodate the required range of body sizes, the width and height of the shoulder supports and the location of the aircraft controls are adjustable.

In the photographs, Figures 11 and 12, a subject is shown in the upright and reclined positions, while Figures 13 and 14 show the restraint system being evaluated under conditions of - 1 G_y and -1 G_z, respectively. Evaluation of the powered mobility feature is depicted in Figure 15.

A close-up photograph of the seat assembly is given in Figure 16 and details of the backrest can be seen in Figure 17 in which the backpad and contour-forming seat pad have been removed. The basic restraint system and the inflatable bladder restraint systems are shown in these photographs. The inertia reel for the shoulder straps is mounted on the shelf above and behind the upper backrest segment while the inertia reel for the chest restraint straps is located on the aft surface of the center backrest segment. Both inertia reel controls are on the left side of the mock-up. The electrical actuators for the backrest and headrest are located in the compartment behind the backrest and the actuator shafts are visible in Figure 17, in which the backrest and headrest are rotated to the right. Both actuators are controlled by a single toggle switch incorporated in the side-stick controller. The inflatable restraint system can also be seen in Figure 17. The bladders are enclosed by stretch nylon-frothed neoprene covers which control the inflated shape. Compressed air or nitrogen is distributed to the bladders from an external supply through a pressure regulator and a network of flexible tubing. The regulator and a pressure bleed valve are mounted in the rear of the mock-up. The contour-forming seat pad is controlled by a self-contained pressure-vacuum unit. This is mounted in the rear compartment so that the control switch can be reached through the access port on the left side.

<u>Restraint System</u>

The combination of the strap and inflatable restraint systems provided excellent support and restraint in all rotation positions in both the upright and reclined configurations. An inflation pressure in the 2-to-3 psi range appeared to provide good support and, in the case of the forearm restraint, this pressure resulted in firm restraint without the application of excessive force on the arm. It was possible to remove and replace the arm in the restraint trough with the bladders inflated.

In the inverted position, some effort was required to keep the feet on the rods which represented the rudder pedals and it was considered that this could become a nuisance at higher values of $-G_z$. A reasonable approach would be to provide some form of mechanical restraint to help retain the feet on the rudder pedals.

In the mock-up, the take-up of the chest-strap inertia reel was not sufficiently positive. This was apparently due to excessive friction caused by the strap routing. This problem could be overcome by improving the installation. However, there is possibility that these restraint straps may not be required and it is recommended that this approach be investigated in any future development program.

Powered Mobility System

Demonstration and evaluation of the powered backrest and headrest indicated that such a system could be a practical method of obtaining external visibility under conditions where the pilot is essentially pinned in the seat by the maneuver acceleration forces. On the basis of the mock-up evaluation, it was considered that the external vision envelope would be improved if the headrest was tilted aft during rotation to increase the upward and aft field-of-view. The rotation rate of the mockup system is relatively low and a much higher rate would be required for an operational system. From the evaluation of the mock-up, it was concluded that there was no indication that a significant increase in rotation rate would cause problems.

Contour Forming Cushion

The contour-forming cushion used as the seat pad in the mock-up was demonstrated to conform exactly to the shape of the person sitting on it. The cushion was used with a flat seat pan and a one-inch foam pad was inserted between the cushion and the seat pan. This arrangement was found to be satisfactory.

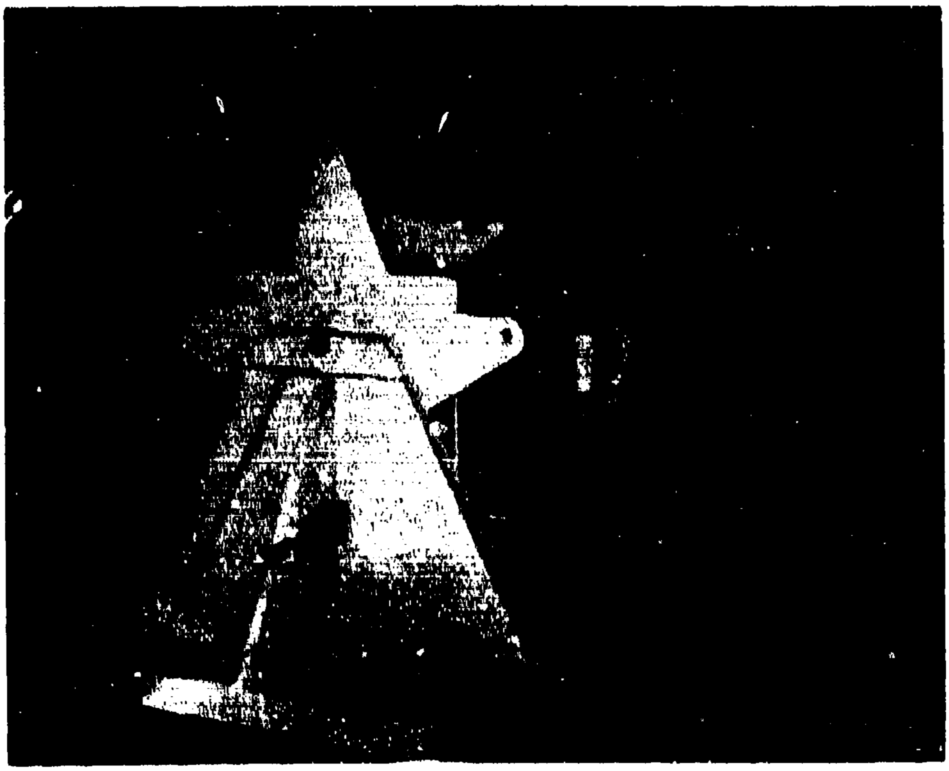

FIGURE 10. CONCEPT EVALUATION MOCK-UP

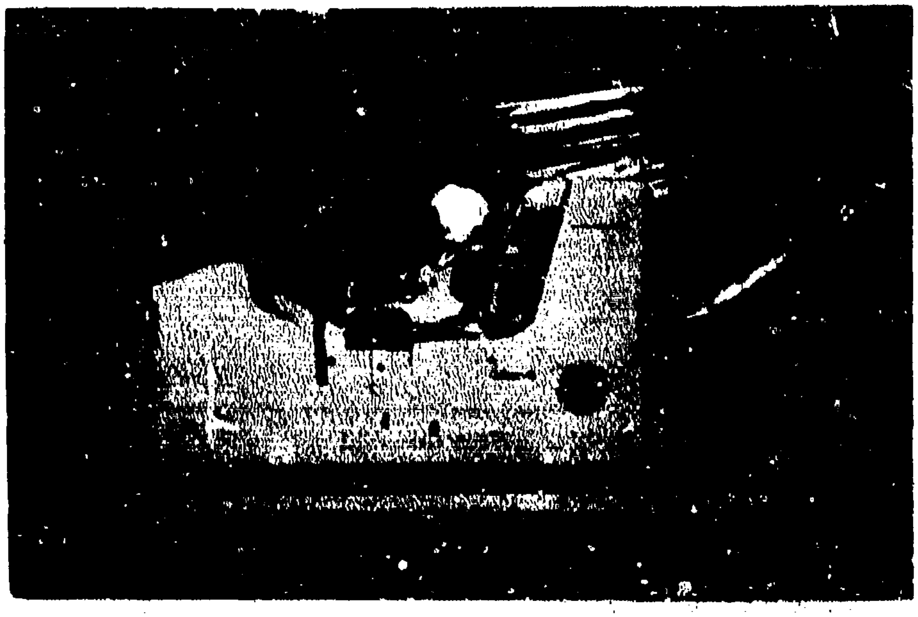

FIGURE 11. SUBJECT IN UPRIGHT CONFIGURATION

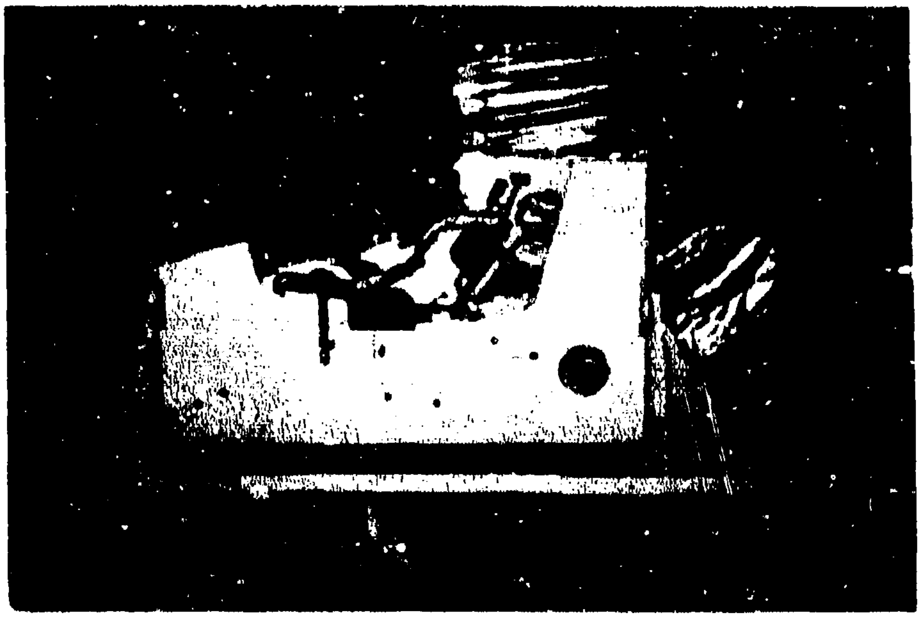

FIGURE 12. SUBJECT IN RECLINED CONFIGURATION

FIGURE 13. EVALUATION AT -1 G_y

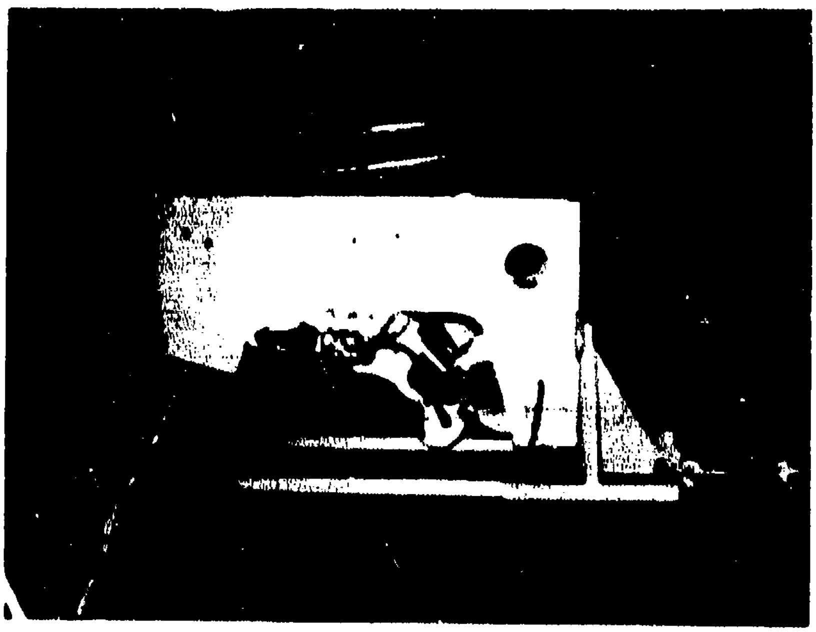

FIGURE 14. EVALUATION AT -1 G_z

FIGURE 15. POWERED MOBILITY EVALUATION

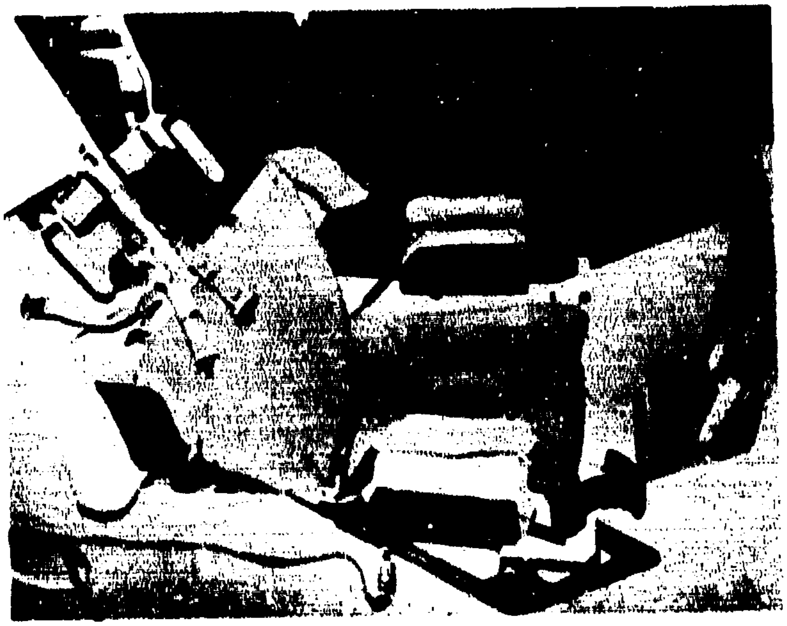

FIGURE 16. SEAT ASSEMBLY

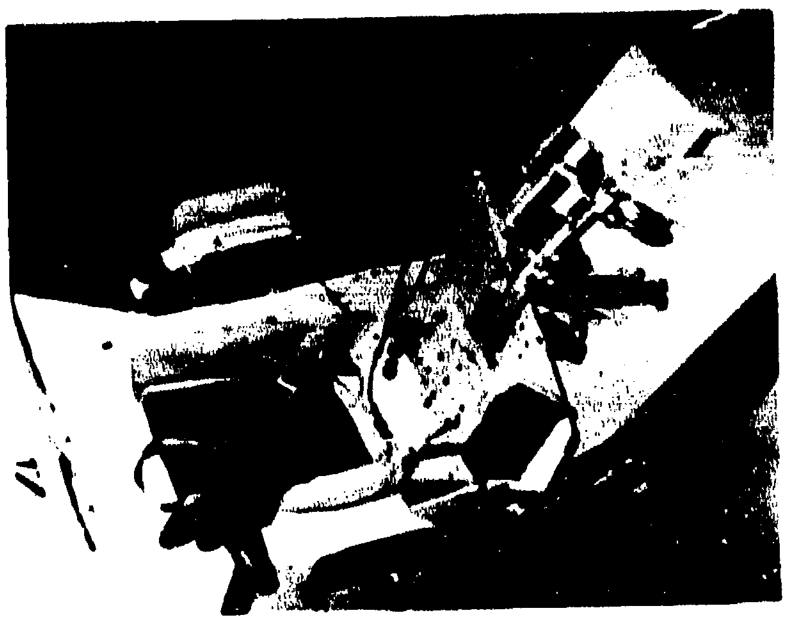

FIGURE 17. SEAT ASSEMBLY COMPONENTS

CONCLUSIONS

In this program, two conceptual approaches for advanced design aircrew restraint and protection systems were studied as potential solutions for satisfying the requirements projected for the next generation of Air Force combat aircraft. The conclusions resulting from the evaluation of these two concepts are:

SPHERICAL CAPSULE CONCEPT

The spherical capsule concept appears to have the potential of satisfying all of the aircrew restraint and protection requirements projected for the next generation aircraft. However, there are several fundamental aspects of the concept which would have to be proven before the concept could be considered to be a practical design approach. Two primary aspects of the concept, the unique posture and the use of lateral rotation for restraint and for surveillance, may prove to be incompatible with the mission or with the operation of the aircraft. Also, two design areas, vision characteristics through the double transparency and the packaging of the displays and controls within the capsule, could present intractable design problems. It was concluded that the technical risk was too high and the development program too extensive to permit selection of the capsule as the primary program for obtaining advanced aircrew systems for the next generation of Air Force aircraft.

ARTICULATING SEAT CONCEPT

The articulating seat concept studied does not have the high altitude, high speed protection capability of the capsule concept. However, it was concluded that an articulating seat can be equipped with advanced design subsystems which will meet the projected next-generation requirements for restraint, mobility and escape under high acceleration maneuver conditions.

Evaluation of the mock-up articulating seat incorporating advanced design restraint and mobility subsystems indicated the following:

- A system of inflatable bladders, used in conjunction with a strap-type basic restraint system and with a contour-forming seat cushion, provides excellent aircrew restraint and support. The evaluation was limited to conditions of $\pm 1\ G_z$ and $\pm 1\ G_y$ and evaluation under higher acceleration conditions will be required to determine the full capability of this concept.

- A powered backrest and headrest system was demonstrated and appeared to be a feasible method of providing aircrew mobility for external visibility under high-maneuver conditions in which the crewman must be fully restrained. Evaluation of the mockup revealed areas of potential improvement, rotation authority and head motion which should be the subject of additional study. Testing under representative acceleration conditions will be required to determine the effectiveness of this concept in terms of external visibility and to establish design characteristics such as rotation rate and excursion limits.

For emergency escape, it was concluded that an articulating seat could be equipped with advanced design subsystems which had the potential of meeting the requirements for escape under the projected high-acceleration maneuver conditions. The system would have selectable propulsion thrust, thrust vector control and an inflatable stabilizer-decelerator system. The escape system would be controlled by a microprocessor and an environment-sensing system which would match the subsystem operation and performance to the emergency environment. It was further concluded that a system of this type also had the potential for reducing escape-system related injuries for escape under those conditions where maximum performance escape forces are not required.

RECOMMENDATIONS

In this program it, was concluded that the capsule concept and the concept based on the articulating seat both had potential with regard to the provision of improved aircrew escape systems in future aircraft. Recommendations for future effort are:

CAPSULE CONCEPT

The capsule concept has the potential for meeting all of the projected requirements for the next generation aircraft, and it is recommended that additional studies be conducted to investigate the high-risk aspects of the concept and to determine whether or not the apparent potential can be realized. The specific areas in question are: posture, lateral rotation, optical characteristics and packaging of displays and controls. It is envisaged that the necessary information on these aspects could be obtained by a combination of design studies and exploratory centrifuge and simulator testing.

ARTICULATING SEAT CONCEPT

The restraint and mobility aspects of this concept were demonstrated and evaluated under $\pm 1\ G_z$ and $\pm 1\ G_y$ conditions using the wooden mock-up. The results of this evaluation were encouraging and it is recommended that the subsystem concepts:

- o inflatable restraint and support
- o contour forming cushions
- o powered backrest and headrest

be incorporated in a seat assembly test fixture which could be used in a series of centrifuge tests to evaluate the function and effectiveness of the concepts under representative multiaxial acceleration conditions.

ESCAPE SYSTEM CONCEPT

The escape system proposed as part of the articulating seat concept would meet the projected requirement for escape under multiaxial acceleration conditions. The proposed system would also have the capability to select and control seat system operation and performance to match the emergency conditions throughout the escape envelope. This system is considered to be the "next-generation" ejection seat system which has the potential for significant improvements in capability and performance while reducing the overall incidence of injuries. It is recommended that a study program be initiated to cover the preliminary design definition of this system.

APPENDIX

TECHNICAL COMPARISON

INTRODUCTION

The capsule and articulating seat concepts were evaluated and the articulating seat concept was selected for further study in the mock-up phase of the program. The selection was based on a technical comparison and on an assessment of the overall development programs which would be required to ensure the availability of improved aircrew provisions for the next generation of Air Force aircraft. This appendix describes the technical comparison. The technical comparison rated the capsule concept higher than the articulating seat concept; however, as previously described, the articulating seat concept was selected because of the greater probability of the successful development of improved aircrew systems for the next generation aircraft.

COMPARISON PROCEDURE

The technical comparison of the two concepts was made relative to the following specified factors and weightings:

Factor	Weighting
Safety	35%
Performance	35%
Comfort	20%
Reliability and Maintainability	10%

To obtain a comparison at a sufficient level of detail, each of the specified factors was broken down into its primary elements. In the case of "safety," because of the diverse areas covered, this factor was divided into three subfactors which were assigned weightings. Each subfactor was then broken down into its primary elements. The subfactors and assigned weightings are:

Safety Subfactor	Weighting
Protective Restraint	20%
Protection in Flight Emergencies	30%
Escape	50%

COMPARISON RESULTS

The detail comparison of the two concepts is given in Tables 1, 2, 3, 5 and 6 and the weighted summation for the "safety" comparison is given in Table 4. Examination of these tables shows that the capsule concept was rated to be superior with regard to "safety" and "performance" and the articulating seat concept was superior in terms of "comfort" and "reliability and maintainability." The "safety" rating for the capsule, Table 4, is primarily a reflection of the fact that the capsule provides aircrew protection at high altitude and against windblast at high speed. The superior "performance" rating for the capsule, Table 5, is based on the assumption that lateral rotation is compatible with flight and combat operations and that lateral rotation can be utilized to obtain an improved visual target acquisition and tracking capability. The low "comfort" rating for the capsule, Table 6, is entirely due to questions regarding the cross-legged posture. This assessment assumes that the cross-legged posture will result in comfort problems, physiological and psychological, which may be difficult to resolve. The "reliability and maintainability" rating, as indicated in Table 7, is based simply on the relative complexity and accessibililty characteristics of the two concepts.

The overall results of the technical comparison, Table 8, shows that the capsule is rated superior to the articulating seat concept.

TABLE 1. SAFETY - PROTECTIVE RESTRAINT

CONDITIONS	CONCEPT RATING ARTICULATING SEAT	CONCEPT RATING SPHERICAL CAPSULE
Maneuvers, Turbulence	Good	Good
Articulation	Good	Good
Pre-ejection Articulation	Fair	Fair
Ejection	Fair	Excellent
Aero and Deceleration	Fair	Good
Recovery Chute	Fair	Good
Ground Crash	Fair	Fair
EVALUATION	12/20	16/20

TABLE 2. SAFETY - FLIGHT EMERGENCY PROTECTION

CONDITIONS	CONCEPT RATING ARTICULATING SEAT	CONCEPT RATING SPHERICAL CAPSULE
Loss of Pressurization	Poor	Good
Loss of Canopy	Poor	Good
Bird Strike	Fair	Good
Fire	Fair	Good
Loss of Oxygen	Fair	Good
Enemy Strike	Fair	Good
Seat/Capsule Malfunction	Fair	Poor
EVALUATION	15/30	22/30

TABLE 3. SAFETY - ESCAPE CAPABILITY

CONDITIONS	CONCEPT RATING ARTICULATING SEAT	SPHERICAL CAPSULE
Pre-ejection Functions	Poor	Poor
Maneuver - Spin	Fair	Good
High Altitude	No	Good
High Speed	Poor	Good
Low Speed · Low Altitude	Good	Good
Sink, Adverse Attitude	Good	Fair
Protection during Recovery	Poor	Good
Ground Impact	Fair	Good
Survival	Fair	Good
Emergency Ground Egress	Good	Fair
EVALUATION	30/50	45/50

TABLE 4. SAFETY EVALUATION SUMMARY

SAFETY FACTOR	WEIGHTING	CONCEPT RATING ARTICULATING SEAT	SPHERICAL CAPSULE
Protective Restraint	20	12	16
Flight Emergency Protection	30	15	22
Escape Capability	50	30	45
	EVALUATION	57%	83%

TABLE 5. PERFORMANCE

FACTOR	CONCEPT EVALUATION ARTICULATING SEAT	SPHERICAL CAPSULE
External Visibility - Upright	Baseline	Degraded Improved with Rotation
External Visibility - Reclined	Powered Twist	Rotation
Internal Visibility	Baseline	Degraded
Aircraft Control	Baseline	Fly-By-Wire Rudder Aircraft-Crewman Axes
G Protection	Baseline	Improved with Rotation
Target Acquisition	Baseline	Improved with Rotation
Target Tracking	Baseline	Improved with Rotation
EVALUATION	25/35	30/35

TABLE 6. COMFORT

FACTOR	CONCEPT EVALUATION ARTICULATING SEAT	SPHERICAL CAPSULE
Upright	Baseline	Cross-Legged Pulsating G-Suit
Reclined	Baseline	Leg Improvement
Restraint	Baseline	Less Hardware
Clothing and Equipment	Baseline	No Life Preserver No Survival Vest
EVALUATION	15/20	10/20

TABLE 7. RELIABILITY AND MAINTAINABILITY

CONCEPT COMPARISON

	ARTICULATING SEAT	SPHERICAL CAPSULE
Reliability	Articulating Mech Emergency Retraction Leg Restraint Bladder Systems Rudder and Brake Mech	Pitch Rotation Mechanism Emergency Rotation Lateral Rotation Bladder Systems Pulsation Feature Umbilical Guide Rail Mechanism More Fly-By-Wire
Maintainability	Baseline	Additional Systems Cockpit Access Degraded Access From Outside
EVALUATION	7/10	4/10

TABLE 8. EVALUATION SUMMARY

FACTOR	SPECIFIED WEIGHTING	CONCEPT RATING ARTICULATING SEAT	CONCEPT RATING SPHERICAL CAPSULE
Safety	(35)	20	29
Performance	(35)	25	30
Comfort	(20)	15	10
Reliability	(10)	7	4
OVERALL EVALUATION TOTAL		67%	73%

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